

Cowles Dissolver Fire Involving IR Flare Mix

By

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Abstract

In November, 1993, a fire occurred in a Cowles Dissolver while mixing infrared decoy flare composition. The major constituents of the mix were magnesium, polytetra-fluoroethylene (PTFE), and a fluoroelastomer binder dissolved in acetone. Hexane is used to precipitate the binder and wash the mix. During the wash cycle, ignition occurred and consumed the mix. There were no injuries but significant heat damage was evident in the mixer bay. Deluge, blow-out walls and other safety features functioned as intended.

A Board of Investigation composed of both Government and Contractor personnel was convened to determine the most probable cause. The Board concluded that the most probable cause for the fire was either ESD or friction. Subsequent efforts by Contractor personnel to quantify the electrostatic hazards of the system were not able to duplicate an ESD scenario. Field tests to evaluate the friction scenario were not completed.

This paper will summarize the event and the subsequent testing to isolate the cause. The final conclusion was that, while ESD seems unlikely, it cannot be ruled out, nor can friction conclusively be proven to be the cause.

Introduction

Thiokol Corporation is the operating contractor of Longhorn Army Ammunition Plant in Karnack, Texas. Thiokol is a long time producer of pyrotechnic items and rocket motors at this location. One such family of items is infrared decoy flares. Several mixing methods are used to manufacture the flare compositions, including the use of a Cowles Dissolver in the "shock precipitation" method.

The major ingredients in the flare composition are magnesium powder, polytetrafluoroethylene (PTFE), and a fluoroelastomer binder. The fluoroelastomer binder is dissolved in acetone before the mix is made. The PTFE and magnesium powder are suspended in the binder solution by the action of the high shear Cowles Dissolver blade. Hexane is rapidly added to the stirred suspension and the binder precipitates on the surface of the suspended particles. The solids are allowed to settle and the liquid is siphoned from the mix bowl. Hexane is used to wash the solids and the wash is siphoned from the bowl two times. The solids are then removed and dried for transfer to an extruder for processing.

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The location where the mixing of the composition is performed is Building 54-H, Bays R-109 and R-110. The mixing of the flare composition is a remote operation performed by a crew leader and two operators located in a control room. These operators control the mixing process with the aid of video monitors and electronic remote control devices. Flare composition is normally mixed concurrently in Bays R-109 and R-110. The mixing operation is protected by a combination of passive and active features. The two mixer bays have substantial dividing walls on three sides and a pressure relief wall on the front of the bays. There were approximately 450 square feet of surface area for pressure relief. There are fire doors located on both ends of the mixing bays plus a third fire door in the hallway leading to the control room. The building was equipped with a sprinkler system and each bay had a rapid response deluge system utilizing UV detectors and high speed valves.

Mix Procedure

Figure 1. Flow Diagram for Cowles Dissolver Process

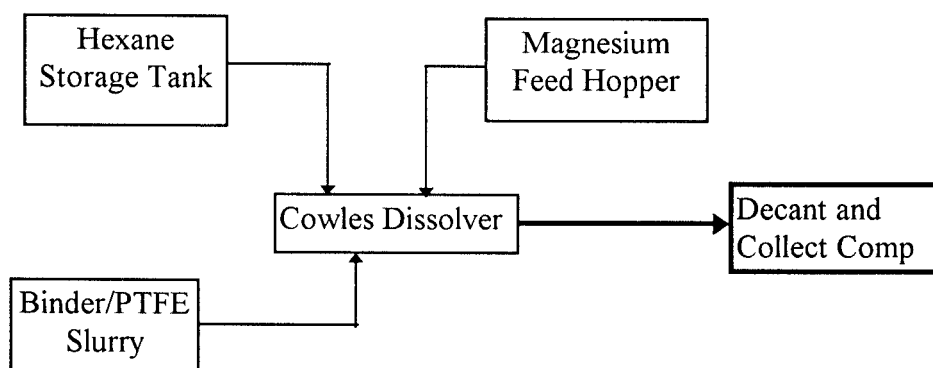


Figure 1. Flow Diagram for Cowles Dissolver Process

The mixing cycle begins with the weigh up of the fuel and oxidizer in separate facilities. The solids are transported to Building 54-H as required. The binder/acetone mixture is procured as a solution, ready to mix.

The mixing day begins with the crew performing pre-operational checks of the building and equipment. The fuel (magnesium) hoppers located in the mixing bays are loaded manually by the operators. The mixing bowls are positioned in Bay 108 and loaded with pre-metered amounts of the acetone/binder solution. The pre-weighed PTFE is added to the bowls and the bowls are transferred to the mixing bays. The bowls are manually positioned under the Cowles Dissolver and the cart frame is locked into position against fixed stops. The operators return to the control room and begin the remote mixing process.

The process is controlled and timed by computer interface. The operator is required to push indicator buttons at the end of each processing step to confirm completion of each operation before the next operation can begin. The mix procedure is detailed in the following steps:

Step No.	Description
1.	A three (3) minute mix to combine the PTFE and binder mixture.
2.	The operator dumps the magnesium powder into the mix from a remote hopper.
3.	Mix the slurry for approximately 10 minutes to assure thorough dispersion of all of the solids in the binder solution.
4.	The addition of approximately 32 gallons of hexane to the mix. This step “shock precipitates” the binder out of the acetone while the Cowles blade keeps all of the particles in suspension.
5.	Shut the Cowles blade off to allow the coated solids to settle in the mix bowl. After the mix has settled, a decant tube is lowered into the bowl and the hexane/acetone mixture is siphoned from the bowl with a pump.
6.	Start the Cowles blade turning again and add additional hexane to wash the mix.
7.	Stop the Cowles blade and again remove the hexane/acetone mixture.
8.	Start the Cowles blade and wash the mix a second time with hexane.
9.	Stop the Cowles blade and raise the mixing head to allow removal of the bowl to Bay R-111 for dumping and mix recovery.

Another operation occurs when “cross mixing” is used to blend mixes for improved homogeneity. In cross mixing, half of a previous mix (approximately 62 lb) is added to the current mix just prior to the second hexane wash. This gives a total mix of about 187 lb.

Incident Description

On November 2, 1993, the mixing day began at 0600. The first mixes of the day (both bays) were made without incident and set aside for “cross mixing” with the following mixes. The second pair of mixes was started in both bays and proceeded normally up to the point of hexane addition. The hexane failed to pump for the initial “shock” of the binder. Maintenance personnel were called and the problem was corrected by bleeding the hexane pump in the dispensing system. The mixing process was continued through the first hexane wash. After the first wash, the Cowles Dissolver mixing head was raised and approximately half of one of the first mixes was manually added to the mix bowl. The mixing head was lowered and mixing was ready to resume. About this time, Ordnance Operations Safety

Director entered the building to conduct a safety audit. The Production Foreman and the mix crew were also in the control room.

At approximately 1030 hours, during the hexane addition for the second wash, a fire occurred in Bay R-110. All personnel exited the building safely and there were no injuries. Personnel working in the other end of the building also exited safely. The Safety Manager was the last to leave the building after observing that the control room did not experience any overpressures, smoke or flame. Other than the video evidence, those in the control room only noted that it sounded like a big “whoosh”.

At this point, the Safety Manager assumed control of the scene and verified the personnel count and that there were no injuries. After a short period of waiting, the control room was re-entered and it was observed that the television monitor in Bay R-109 was still functioning. A small fire was observed on top of the mixer bowl. It appeared that this mix had not burned. Since the initial concern was that the second mix still had the potential to burn, it was decided to back off from the building and evaluate a course of action. It could not be determined what was feeding the small fire in the bay. It appeared to fluctuate around the top of the mixer bowl. The deluge systems were flowing water in both bays. After about two hours, it was decided that the best course was to attempt to extinguish this small fire. This was accomplished by the Fire Department personnel spraying a small amount of foam from a protected position outside the bay through the blown out wall panels.

An initial survey of the fire scene indicated that all safety measures functioned as designed. The sprinkler and deluge systems activated, pressure relief walls released, fire doors prevented the spread of the fire and the equipment shut down as designed. At this time, the area was secured awaiting the formation of a joint Government/Contractor Board of Investigation.

Incident Investigation

In any incident investigation, it is common practice to develop a fault tree to try to determine the most probable cause of the incident. Infrared decoy flare compositions are very hazardous pyrotechnic compositions that are treated with a great deal of care in manufacture and processing. Indeed, there is a significant history of damage and death from processing these compositions.

In the second wash cycle with hexane, there was an ignition in the bay that resulted in loss of the mix and some damage to the mixing bays. Deluge activation and other safety features worked as planned and there were no personnel injuries due to the incident. After clearing the building of live material, an investigating team composed of AMCCOM safety personnel, local Army safety personnel and contractor personnel was convened. Data were gathered and collated for analysis. A fault tree was established for the incident as shown in Figure 2. The results of the fault tree analysis are outlined in the following paragraphs.

FIGURE 2. FAULT TREE DIAGRAM

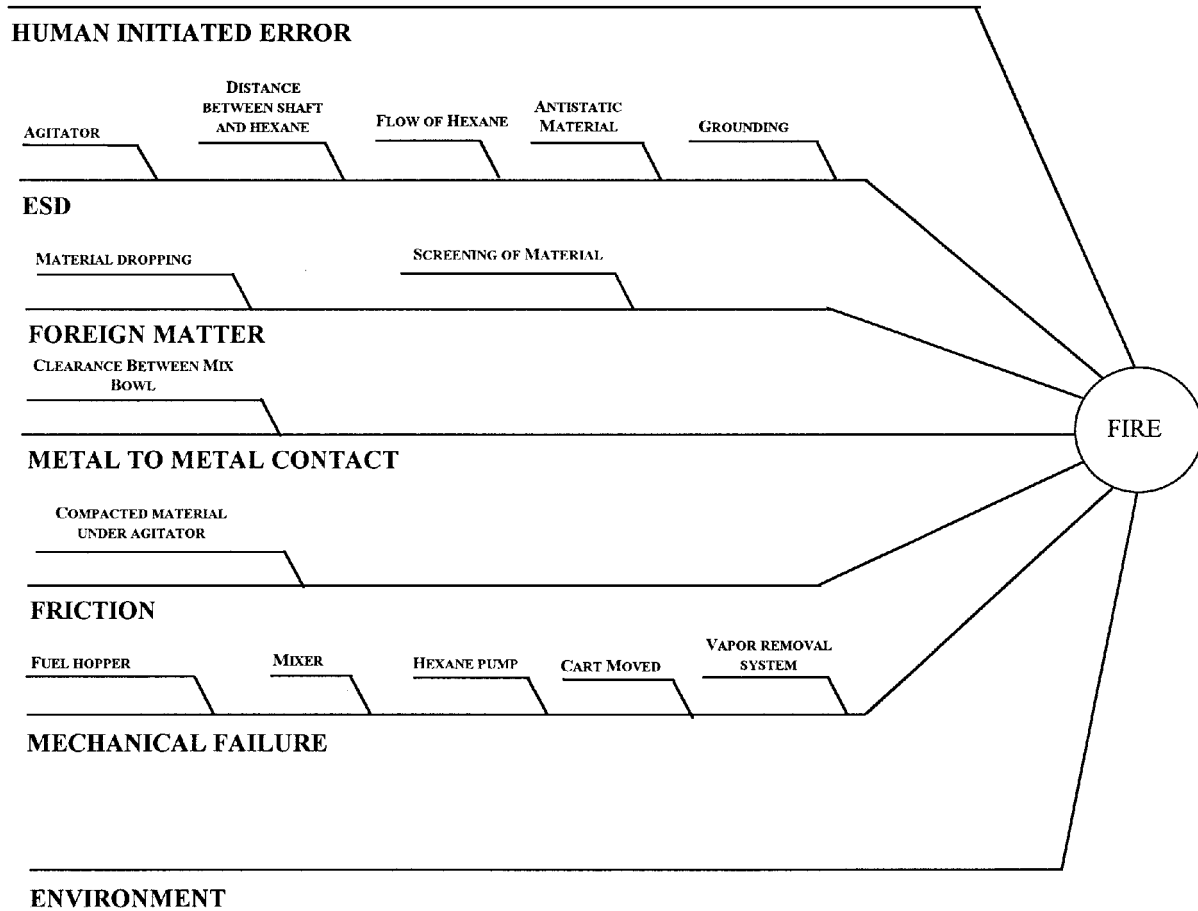


Figure 2. Fault Tree Diagram

Fault Tree Analysis for 54H Incident

Human Initiated Error (HIE)

The personnel in the building all had significant training and experience in the operations. The building foreman is intimately familiar with the operational aspects of all phases of mixing and handling of the raw materials and compositions. Procedures have been reviewed and no evidence of deviations have been noted. The Safety Manager for Thiokol Ordnance Operations and the Thiokol Corporation Safety Director were reviewing safety procedures in the Control Room at the time of the incident. Neither noted any unusual occurrence and the mixer crew followed SOP's through-out the mixing and during the incident. No evidence has been found that indicates any operator error.

Operator awareness of the hazards of these materials makes them very alert for contamination or unusual occurrences.

Electrostatic Discharge (ESD)

Background

A previous fire in 54H was attributed to ESD initiation during the addition of hexane during the mix cycle. In this previous case, the video tape showed the spark initiation at the surface of the liquid and even followed the spark down the mixer vortex followed by eruption of the entire mix from the bowl. This event led to the discovery that the hexane generated a very large static charge, especially as it flowed from the feed pipe. It was felt that the position of the pipe discharge contributed to the spark discharge. From this incident, the addition of hexane was changed to reduce the chance of the configuration contributing to the spark discharge.

Later, an additive made by DuPont (Stadis 450 Conductivity Improver) was identified that increased the static dissipation of hexane. This material is now routinely added to the hexane as it is pumped from tank trucks into the hexane storage tanks. This additive does not prevent the buildup of static charge in hexane but does promote dissipation of the charge by increasing the conductivity of the hexane. The time constant for dissipation is a function of concentration, temperature, grounding path and amount of charge.

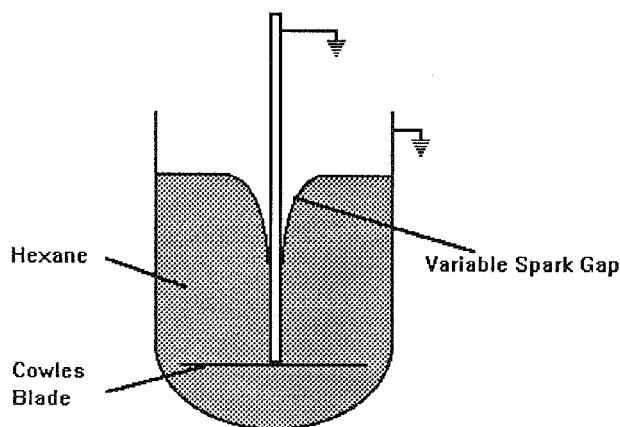
Current Incident

In the current incident, the flare composition had been mixed and rinsed once with hexane. The mix was in the process of recharging with hexane to complete the second wash. Of the 20 gallons of hexane required, it is estimated that 18 gallons had been added to the mixer when the ignition occurred. The video tape of the incident shows the hexane addition was

delayed for approximately 2.5 minutes waiting for the Cowles mechanism to seat so the control panel light would enable the hexane feed switch. The hexane is observed to flow slightly to the left of the shaft. The path appears to be approximately 6 inches from the end of the nozzle to the rotating shaft of the mixer blade. The hexane appeared to spread slightly as opposed to the flow observed from the previous day's mix.

In the process, the Cowles dissolver blade is turning at 800 to 1000 rpm during the addition of hexane. The particles of fuel and oxidizer are being swirled in the mix during the addition. The hexane may pickup a charge as it is discharged from the pipe and this charge will be carried into the bowl.

There are several grounded discharge paths for the charge to follow for dissipation, however, the solvent is only "static dissipative", not conductive. During the mix cycle, the swirling of the particles in the hexane may cause a buildup of charge in the liquid. This charge will continually try to bleed off, but may vary in intensity as a function of speed of mix blade, absolute humidity of the air, ground integrity, etc. If the charge exceeds the breakdown potential for air (25,000 volts/cm), a discharge may occur. The vortex created by the mixer blade/shaft provides a ready path for the discharge to occur to the grounded shaft. The figure below shows this graphically.



In this case, the "semi-conductive" nature of the hexane may allow buildup of a considerable charge in the bulk of the liquid since only a small portion of the hexane actually contacts a grounded path for dissipation. Under the right circumstances, a discharge could occur between the liquid and the grounded shaft. The ignition energy for a flammable concentration of hexane and air is 0.29 millijoules (0.00029 joules). If the concentration of hexane is between 1.25% and 6.90% by volume in air (Lange's Handbook of Chemistry, Ninth Edition), ignition of the hexane vapor will occur from a very small spark. The flash point of hexane is - 7 °F. As shown previously, the sweeping of the hexane flame down into the bulk of the slurry will cause ignition of the entire mixture. The pressure from the burning mixture throws

most of the mix into the air where complete mixing with oxygen in the air results in a huge fireball with pressure to force the fire into other areas. In this case, the blow-out panels in the mixer bays released the pressure to the outside and the event was basically confined to the mixer bay. A small amount of smoke was seen above the fire door to the hallway. The appearance of the bays after the incident, including the apparent lack of damage to the mixer bowl, supports this scenario. This scenario was provided to the Thiokol Science and Engineering Division for concurrence.

The video tape appears to show ignition at the surface near the center of the bowl. If ignition had occurred under the blade, the fire would have had to flow up around the outer edge of the bowl, since the blade would shield the shaft.

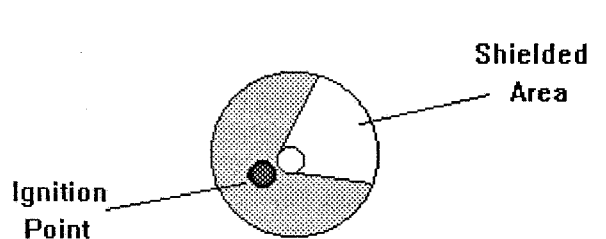
It was observed that there is a layer of charred material on the mixer shaft. This layer is in the region where the hexane pours onto the shaft. It was measured at 22 inches above the bottom of the shaft. The mixer bowl measures approximately 34 inches from the center to the top. The bottom of the shaft is estimated at 2 inches above the bottom of the bowl which means that the top of the layer is estimated at 10 inches below the top of the bowl. It was observed, also, that there is char on the mixer bowl walls that could be related to this binder coating the bowl walls. The area directly under the mixer blade appears to be relatively free of char. When the acetone/binder solution is shocked by the hexane, some of the binder will precipitate on the shaft. Likewise, some of the binder will precipitate on the walls of the mixer bowl. These layers may serve to insulate the shaft and the bowl and reduce the grounding potential of these surfaces. This would aggravate the build-up of electrical charge by reducing the grounding paths to drain the charge. By the time the hexane is added to the mixer bowl, the ground path could be less effective. The area of the mixer shaft above the mix would be uncoated, however, and could serve as a ground point for the electrostatic charge to discharge through. As the last of the hexane enters the bowl, the top of the solvent layer is observed to be about the right level to allow a discharge from the surface of the solvent to the uncoated mixer shaft. This scenario fits the observed ignition on the video tape and the overall pattern for an ESD event to ignite the hexane vapors. Figure 3. shows the position of the pipes, mixer blade and bowl with indicators marked for binder deposits.

A computer simulation was run on the ignition of the hexane vapors in the top of the mixer bowl. The following assumptions were made:

The volume above the mix was 2 ft in diameter by 1 ft in depth for a volume of 5400 in.³ or 88000 cc. Assuming 4% by volume for the hexane (the middle of the explosive limits) gives 3700 cc of hexane vapors. With a molecular weight of 86 gm/mol, this translates into about 12 grams or 0.03 lb of hexane. Using the Vapor Cloud Explosion Damage Assessment Model (VEXDAM+) from Engineering Analysis, Inc, the following scenario was set up. Using 0.03 lb of hexane at a category 7 ignition (where category 10 is a detonation with shock wave), a calculation of the pressure generated by ignition of this vapor cloud showed 15 psi

of pressure within the mixer bowl. Changing to a category 8 event shows a calculated pressure in the mixer bowl of 29 psi. The category 6 event predicts only 1.7 psi in the mixer bowl. Based on the observations from the video tapes, it is felt that the event was probably between the category 7 and category 8 events. This means that the pressure generated from the hexane ignition alone would have exerted about 9900 ∇ 3500 lbs of force down on the surface of the mix.

From the tape, the ignition occurring on the front side of the bowl would have allowed the shaft to shield the back side of the bowl from the pressure wave and generated an unbalanced force on the mix. This unbalanced force would have forced the mix down and out the back of the bowl and into the back side of the bay. Examination of the heavy ash deposits in the back of Bay R-110 suggests that this did occur. In this scenario, the hexane ignition alone would have been sufficient to blow the panels off the outside wall and the mix would have ignited as the hexane vapors were driven off of the mix as it splattered throughout the back of the bay. The main fireball from the flare composition would have been reduced somewhat by the action of the deluge water absorbing some of the heat. The video tape frames after the ignition also support continued burning within the bay for a significant time after the main fireball from the mixer bowl.



These conclusions do not alter the recommended actions to improve the handling and safety of the mix.

Recommendations

It appears unlikely that absolutely positive elimination of static charge buildup in a "semi-conductive" solvent like hexane can be achieved. Addition of the DuPont additive should be continued to minimize the time required for dissipation of charge from the hexane.

Discussions with vendors and some laboratory tests showed that blanketing of the mixer bowl with an inert gas is not practical and the concept was abandoned. A series of tests were arranged using sophisticated ESD detection equipment to try to duplicate the conditions during mixing and determine the probability of an ESD event. A technical paper describing

these tests will be presented at a later date. The test measurements did not indicate that significant electrostatic charge was being generated in the acetone, hexane or combinations thereof. While these tests were unable to detect buildup of a charge sufficient to cause a discharge, they did not completely rule out the possibility that some test variables were not duplicated from the incident. Accordingly, additional tests are needed to better quantify the conditions required for a static discharge to occur.

Metal-to-Metal Contact

Examination of the mixer bowl from Bay R-110 showed no evidence of metal-to-metal contact. No significant foreign material was found in the mixer bowl that was not likely to have fallen in after the fire.

Previous experience has shown that accidental contact of the mixer blade with the bowl wall did not produce an ignition. The wet flare composition is not very friction or impact sensitive (based on laboratory tests.) Ignition of the hexane by metal-to-metal contact is not possible. The video tapes of the mixing operation do not support metal-to-metal contact.

A small scratch observed in the mixer bowl from Bay R-110 was caused after the incident. This is evident by the fact that the scratch is not deep in the metal and goes across two areas of soot. If the scratch had existed before the incident, the scratch would have been covered by the soot.

Friction

Background

At one point in the past, it was found that some of the oxidizer added to a mixer bowl in 54H had become trapped under the Cowles blade and had apparently remained under the blade during the mix cycle. The material had fused into a solid mass. The way the oxidizer is added in the 54H complex requires the mix blade to be above the mixer bowl during the dump. As the blade is lowered, rotation is started when the blade contacts the liquid surface. This is intended to move the material from under the blade before it reaches the full down position.

In at least one documented case, oxidizer did not clear from under the blade and the curved bottom of the mixer bowl apparently kept the material in place during the run. In this case, there was a fire in the opposite bay and the mixer bowl again sat for several days. Under normal mix procedures, the operators raise the mixer blade and adjust the rpms to "lift" the mix and disperse it. This compacted material has never been seen at the end of a normal

(complete) mix cycle. It is likely that this occurs to some degree in every mix at some point in the run.

Current Incident

In the blending operation being run in 54H at the time of the incident, wet pre-mixed flare composition is added to the mixer bowl while the mixer blade is in the raised position. The mixer blade starts rotation as it comes down to the hexane surface. It appears likely that some material becomes trapped under the blade as it reaches the full down position. If the material is packed tightly and cannot flow from under the blade, there would be differential rotation between either the bottom of the bowl and the composition on the blade, or between the blade and the composition on the bottom of the bowl. If solvent could not flow in the area, heat could build up. The flare composition is not friction sensitive and it is questionable that sufficient heat could be developed in a localized spot to ignite the flare composition. If ignition occurred at the bottom of the mixer blade, however, there should not have been any indication of a surface glow before the full mix erupted from the bowl.

In reviewing the video of the incident, it was noted that the Cowles mechanism did not settle readily into the mix. It appeared to "hang up" for approximately 2.5 minutes beyond the normal seating time. The operators reported that this was unusual and it explains why they waited so long to begin hexane addition. The Bay R-109 mechanism seated in the normal time frame. The Bay R-110 mechanism took longer. Until the mechanism is seated, the hexane addition cannot be started. There is a limit switch to preclude addition before the mechanism is seated.

While the Cowles mechanism was seating in Bay R-110, the hexane pipe was observed to undergo severe vibration. The vibration seemed to lessen and intensify alternately over a significant time period. After an extended time, the vibration apparently stopped and the mechanism was seated.

One suggested explanation for the delay in seating and the hexane pipe vibration is the entrapment of material under the Cowles blade. The blade is observed to be spinning from the time it entered the slurry until the mechanism finally seats. While not conclusive, it seems fairly unlikely that material could be packed under the blade in this circumstance. Since the vibration stopped before the mechanism was seated, trapped material contributing to a frictional heat build-up seems remote.

Another possibility for the vibration involves the flow controller for the hydraulics that raise the mechanism. The Cowles mechanism is raised by applying hydraulic pressure to a cylinder. The system closes, however, by gravity pushing the hydraulic back through a flow controller. A check valve in the system allows the flow to quickly raise the cylinder while the needle valve on the flow controller slows the lowering of the mechanism. If the flow controller was having a problem, this could also induce the vibrations in the system and the

hexane pipe is attached at the top of the mechanism and has a long moment arm that would cause it to respond to the vibration from the flow controller. The flow controller should be checked for proper operation after removal from the system.

Since the video review appears to indicate a surface glow before the eruption of the mix, it is considered unlikely that ignition occurred from friction at the bottom of the mix. Close examination of the mixer blade when the bowl was removed supports this postulation. Enhancement of the video frames during the ignition sequence appears to confirm the area near the mixer blade shaft as the ignition site.

Tests have been proposed to investigate the frictional heating mechanism in simulation, however funding and scheduling have not permitted these to be conducted at this time.

Recommendations

The requirement to raise the blades for ingredient addition in 54H stems from the use of removable bowls. The removable bowls were implemented in the installation to permit removal of the mixer bowls for dumping and recharging while a new set of bowls were positioned in the mixer bays for mixing. On a practical basis, it has been found unnecessary and impractical to run the building in this fashion.

The positioning of the vent system and other items mounted on the Cowles mixing system was chosen for convenience in the operations. If the vent system is moved around to the backside of the mixer bowl, room will be provided near the front side of the mixer bowl to allow dumping of materials into the mixer bowl with the mixing blade in the full-down and seated position.

This configuration would eliminate the possibility of material being trapped under the mixer blade.

A checklist item should be added to the SOP to observe the movement of the Cowles mixing system as it lowers. If excessive time or vibration is noticed, the flow controller should be checked for proper operation.

Foreign Material

Examination of the interior of the mixer bowls was the primary means of investigating the presence of any foreign material in the mixer bowl. Both bowls were screened and checked for the presence of any foreign material. The few pieces of material found in the Bay R-110 mixer bowl entered after the fire and would not have caused an ignition. No foreign material was found in the Bay R-109 mixer bowl.

Since the mix is not very impact sensitive and the presence of a large volume of liquid solvent would tend to absorb heat generated by impact of something with the mixer blade, this mechanism is considered unlikely.

Nothing was observed to drop into the mixer bowl during the video tape review of the mix. While not conclusive, it appears unlikely that any large item could have been introduced into the mixer bowl during material addition. The raw materials are screened through an 8 mesh screen before addition to the mixer bowl. The previous mix that was added for cross-blending had been made under the same screening conditions and SOP controls throughout the plant should preclude foreign material contamination of a mix by any significant item.

Mechanical Failure

Fuel Hopper

On entering the Bay R-110, it was noted that the fuel hopper was out of normal position. The fuel hopper is usually raised clear of the mixer bowl by a pair of hydraulic cylinders mounted on the wall. The long cylinder lowers the hopper to the load position for addition of the fuel prior to starting a mix. After loading, the cylinder raises the hopper to the dump position. An upper hydraulic cylinder raises the assembly higher to allow positioning of the mixer bowl and access to the bowl for dumping material into the bowl.

If the hydraulic system failed and allowed the fuel hopper to fall during a mix cycle, the weight of the hopper could deflect the mixer bowl out of position, causing the blade to impact the bowl, the bowl wall be brought nearer to the hexane tube thus increasing the possibility of an electrostatic discharge, or causing the bowl wall to impact the hexane tube.

It can be seen from the video tape that the fuel feed hopper did not fall before the incident. After examination of the area, it was seen that the hydraulic lines to the cylinders were burned in two by the fire and the hopper fell as a result of the fire and this mechanism is excluded.

Mixer

Any mechanical failure of the mixer should have produced a visible indication on the video or will be noted from the examination of the mixer after removal of the mixer bowl. The external appearance of the mixer and mixer bowl makes mechanical failure of the mixer system unlikely.

The only unusual occurrence observed on the video tape of the incident involved the rather vigorous vibration of the hexane pipe as the mixing blade was lowering and prior to seating of the Cowles system. The vibration occurred while the system was nearing the bottom position and stopped before the system seated. The cause of the vibration and the implications were

discussed in an earlier section. The flow pattern from the nozzle appeared to be less uniform than that observed on the tape from the previous day.

Hexane Pump

Early in the mix cycle, there was a failure of the hexane pump at the hexane storage tank site. A pipefitter went to the site to correct the problem. He observed some material had leaked from the vicinity of one of the pumps. The pump problem was corrected and the mixing continued.

The flow of hexane was observed to be less ordered from the end of the pipe. This may have been caused by the problems with the hexane system, although the flow in Bay R-109 did not show any change. A more erratic spray of hexane through the air could contribute a slightly greater charge to the hexane as it flows into the mixer bowl. From the video tape, the point of ignition appears to be in the vicinity between the end of the hexane pipe and the rotating, grounded shaft of the mixer blade. Contribution of the charged hexane stream cannot be ruled out.

Vapor Removal System

The vapor removal system appeared to be intact and working at the time of the incident. The sweep of hexane vapors from the mixer serves mainly to keep the hexane vapor concentration in the rest of the bay from reaching the lower explosive limit (LEL = 1.25 volume %) for hexane and air. There is no indication from the LEL meter in the bay that the hexane limit had been exceeded. The normal sweep of air across the mixer bowl and into the vent tube should not cause any additional hazard. The vapor and air concentration near the surface of the mix is likely to be in the explosive region during the mix. The system is not designed to preclude operating between the LEL and upper explosive limit (UEL = 6.90 volume %) within the mix bowl. The vacuum sweep should be continued to maintain overall bay conditions below the LEL.

Bowl Cart

The bowl cart in Bay R-110 was observed to be out of position after inspection of the bay following the incident. The rear locking mechanisms were on top of the locking bar and the cart was observed to be approximately 1 inch back from the normal seating position. The operation of the mixer is interlocked to the locking mechanisms, indicating that the cart was in position at the start of the mix. A review of the video shows that the ignition at the top of the mixer caused a relative motion of the mixer head and the bowl cart. The force of the ignition caused the cart to compress the pneumatic tires on the cart, allowing the cart to drop below the latches. The rebound of the cart moved the cart back to cause the latches to be engaged on top of the latching bar.

The movement of the cart did not occur before the incident and therefore did not contribute to the ignition of the mix.

Environmental

The weather was cloudy and cool, with the relative humidity around 66% and the outside temperature around 50 °F. There was no thunderstorm in the vicinity. There is no chance that a lightning stroke caused any problem within the bay.

The relative humidity and temperature in the mixer bays is controlled.

Conclusions

The fault tree analysis provides a method of documenting the consideration of all factors that can be assigned a value in the investigation. From the fault tree analysis, additional testing may be indicated or a most probable cause may be determined. In addition to considering possible causes, a hazards analysis for each cause allows assignment of a relative probability for the occurrence. By ranking the causes from the fault tree, the most probable one or two scenarios is assigned. Corrective actions are then taken to reduce the probability of ignition even further.

In this incident, there are still two probable causes that cannot be eliminated. Electrostatic discharge ignition of the hexane vapors followed by displacement and ignition of the flare composition cannot be eliminated. Frictional heating of material trapped below the Cowles Dissolver blade cannot be eliminated. Steps have been taken to mitigate both mechanisms in future mixing operations. A new mix procedure that eliminates the need for hexane is under development.

Figure 3. Details of the Cowles Dissolver Configuration

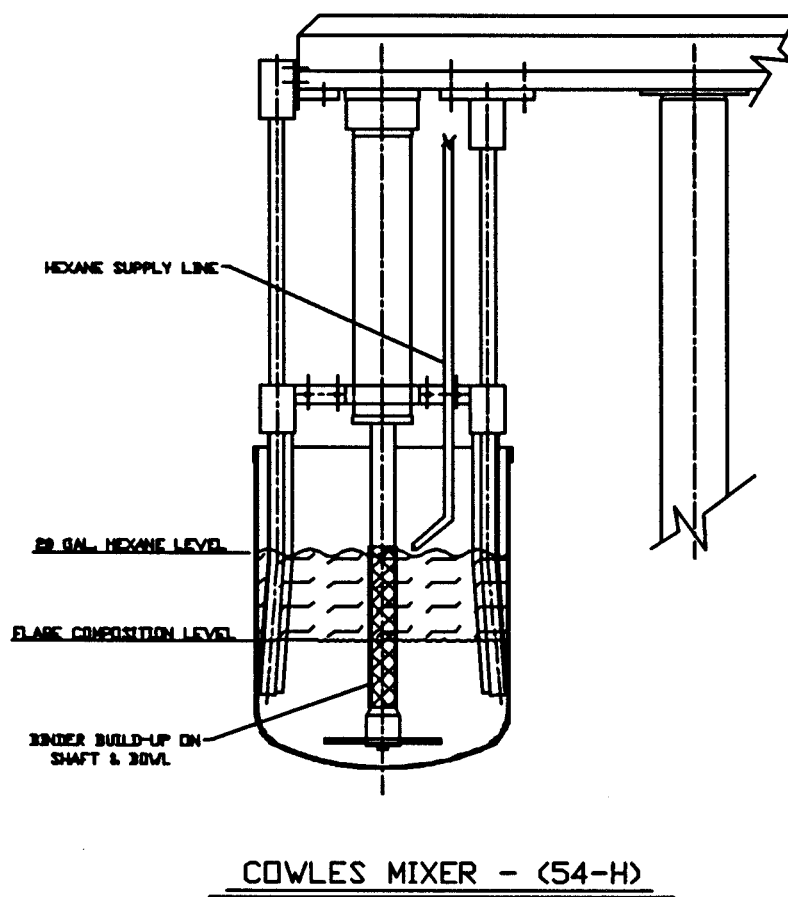


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